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# Performance Analysis of Energy Detection and Cooperative Spectrum Sensing Technique for Cognitive Radio over AWGN and Fading Channels

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**Abstract — Spectrum sensing is the basic and important operation in Cognitive Radio (CR) to find the unused spectrum. This paper focuses on Energy detection because of ease in implementation and Cooperative Spectrum sensing because it doesn't require transmitted signal properties, such as channel information, modulation type. This study concludes the performance analysis of energy detector over Additive White Gaussian Noise (AWGN), Rayleigh fading and Nakagami fading channels. The performance of Cooperative Spectrum Sensing (CSS) with hard decision is also analyzed by means of complementary Receiver Operating Characteristic (ROC) curves for AND rule over AWGN channel. It is revealed through simulation results that CSS with hard combination improves the performance of detection under severe multipath and shadowing problems.**

**Keywords – Cognitive Radio, Energy Detection, Cooperative spectrum sensing, Soft and Hard Decision, Spectrum Sensing.**

## I. Introduction

The proposal of Cognitive radio has been first introduced by (Mitola and Maguire, 1999). Simon Haykin gives the definition of Cognitive Radio, as [1] "Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outer world), and exploit the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., signal transmitted power, carrier signal frequency, and modulation technique) in real-time, with two primary tasks in brain: extremely reliable communications whenever and wherever needed; efficient utilization of the radio spectrum. Cognitive radio is an excellent tool for solving two major problems i) Accessing the spectrum dynamically ii) Interoperability (talking to legacy radios using a variety of incompatible waveforms). In [1] Cognitive Radio technology emerged from the fact that present frequency allocations (with fixed spectrum assignment scheme) confirm that the radio spectrum is highly occupied, i.e. the spectrum scarcity problem for new wireless services and utility, however, it is greatly underutilized (i.e., spectrum is not used effectively). In paper [2] following are the main functions of Cognitive radio cycle has been shown (i) Spectrum Sensing-To determines which portions of the spectrum are available and detect the presence of PU when a user operates in a licensed band. (ii) Spectrum Management- To select the best available channel. (iii) Spectrum Sharing- To coordinate access to this channel with other users.(iv)Spectrum Mobility- To vacate the channel when PU is detected.

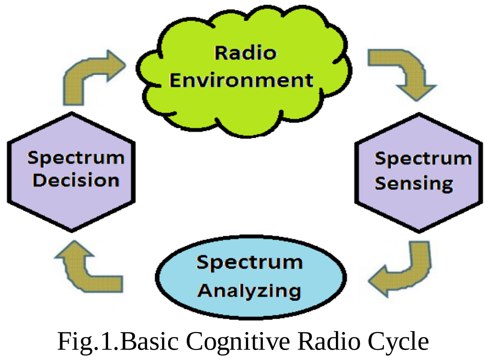


Fig.1.Basic Cognitive Radio Cycle

Cognitive radio systems basically consist of Primary Users (PUs) or Licensed Users (LUs) and Secondary Users (SUs) or Cognitive Radio Users(CRs), in this configuration SUs constantly check the frequency bands to find out if there is a PU transmitting, if not, the band is vacant and the SU can start transmitting its own data until unless a PU comeback. The vacant frequency bands are known as spectrum hole. A spectrum hole is a band of frequencies assigned to PU, but, at a specific time and geographic position the band is free. These spectrum holes can arise in two ways, in time or in space. When a

PU is transmitting in a certain portion of the spectrum at a given time but it is too far away from the SU so that the SU can reuse the frequency, then a spatial spectrum hole exists otherwise if a PU is not transmitting at a given time, then there will be temporal spectrum hole.

The rest of the paper is organized as follows. Section II presents Spectrum Sensing techniques in detail. In Section III system model having all the mathematical analysis carried out is given. In Section IV , results and simulation is presented in which performance of energy detection over AWGN and fading channel is analyzed followed by CSS analysis using AND rule under AWGN channel with all plots. Finally conclusion and discussion is done in the last section V.

## II. Spectrum Sensing Techniques

One of the most important functions of CR is the ability to measure, sense, learn and be aware of the radio parameters such as channel features, availability of spectrum and power, interference and noise temperature, radios operating environment, user requirements as well as applications. In [2] CR, the PUs are referred as the users having license to use the spectrum. Spectrum sensing is a main elements of CR networks which enables CR users to adapt its environment by detecting the spectrum holes (or white spaces) also, it refers to detecting the unused spectrum (spectrum holes or white spaces) and sharing it without causing any interference with other SU. In [3] CR technology, Spectrum sensing is still in its initial stages of development and different sensing techniques are presented for detecting the presence primary signal in transmissions. The most promising way to detect the availability of spectrum holes is to detect the primary signal transmission/ reception of data within the CR range. However, it is complicated to get the measurement of primary transmitter/ receiver channel directly and therefore most of the spectrum sensing techniques presented in [4] focus on the detection of the primary transmitted signal based on the local observations of the CR.

From the above discussion, it can be seen that the primary objectives of Spectrum sensing are as follows:

1. CR users should not cause any harmful interference to the PUs by either switching to an available band or leaving it when PUs came back to use it.
2. CR users should efficiently identify and use the spectrum holes for desired throughput and QoS. In this section we have described different spectrum sensing techniques in [5] detail as follows-

### A. Matched Filter Detection

It is a coherent detection technique i.e. a prior knowledge of the PU signal is required. A matched filter is designed to maximize the signal to noise ratio (SNR) of the received signal. It is obtained by correlating a known signal (or template) with an unknown signal to detect the presence of the template in the unknown signal. In [4] and [6] presented as Matched filter is an optimal method of detecting an unidentified signal. It increases the SNR of received signal in the presence of the additive white Gaussian noise (AWGN) .The transmitted signal from the PU in the presence of AWGN is passed through the matched filter in order to maximize the SNR which is also known as non-coherent detection. The matched filter finds the correlation between the unknown signal with an already known signal to detect the presence or absence of the PU's transmission. The major lead of this technique is that it needs less time to achieve high processing gain due to coherent detection, whereas the disadvantage of this technique is that it needs dedicated sensing receiver for all PU signal types. Also, it is easy to implement because the detector is a linear filter. However, the major constraint is that matched filters are precise to a particular PU signal and can be used to detect only one type of PU signal. For range of PU signals, a series of matched filters is needed for detecting the PUs of interest which will make it more complex hardware requirements and it is not easy to change the detector if new waveforms are introduced or the system evolves.

### A. Cyclostationary Feature Detection

It is a coherent detection process, presented in [5] which Cyclostationary signal means if its autocorrelation is a periodic function of time t with some time period. Due to the periodicity, these signals reveal the features of periodic statistics and correlation. If the PU signals show strong cyclostationary features then PU can be detected at very low SNR values it also requires the prior knowledge of the PU signal. It uses the periodicity in the received PU signal to identify the presence or absence of PUs. In general, the noise and interference do not correlate to time or frequency domain, hence if the SU has prior knowledge about the correlation feature of the PU it can increase the sensing accuracy. The main advantage of this technique is that it is robust to random noise and interference from other modulated signals, no synchronization is required and it gives optimal detection performance in very low SNR region. On the other side it has some limitations such as high computational complexity and long sensing time.

### B. Covariance Detection

Covariance-based signal detection methods were presented in [5] which the statistical covariance matrices or autocorrelations of the signal and noise are normally different. By using the concept that off diagonal elements of the covariance matrix of the received signal are zero when the primary user signal is absent and nonzero when it is present, the researchers in [6] developed two detection methods: (i) covariance absolute value detection and (ii) covariance Frobenius norm detection. These methods are non-coherent as without knowledge of the signal, channel, and noise power various signal

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detection and applications can be done. Further, and by using eigen decomposition of the covariance matrix, the authors further proposed other two detection methods, called max-min eigen value detection and max-eigen value detection in [5] respectively. The importance of the eigen detection methods lies in the significant difference of the eigen value of the received signal covariance matrix when the primary user signal is present or absent.

**C. Wavelet Detection**

It is a non-coherent detection technique, in [6] which Wavelet transform is a multi-resolution analysis system where an input signal is decomposed into different frequency elements, and then each element is considered with resolutions matched to its scales. The wavelet transform uses unevenly shaped wavelets as basic functions and thus proposes essential tools to represent sharp changes and local features. The wavelet technique offers advantages in terms of both implementation cost and flexibility in adapting to the dynamic spectrum, as evaluated to the conventional use of numerous narrow-band band pass filters [9] for signal detection over wide-band channels. So as to discover the locations of vacant frequency bands, the complete wide-band is framed as a train of consecutive frequency sub-bands where the power spectral characteristic is smooth within each sub-band but changes abruptly on the border of two neighboring sub-bands. By using a wavelet transform of the power spectral density (PSD) of the detected signal x(t), the singularities of the PSD S(f) can be located and thus the empty frequency bands can be found. One major challenge of implementing the wavelet technique in practice is the high sampling rates for characterizing the large bandwidth

**D. Energy Detection**

It is non-coherent technique as shown in [4] this technique the RF energy in the channel (or signal strength) is measured to determine whether the channel is idle or not. The method is such that first the input signal is passed through a pre-noise filter to select the bandwidth of interest. The output of filter is then squared and integrated over the inspection interval. Finally, the output of the integrator is compared to a predefined threshold value to deduce the presence or absence of PU signal. However, [7] this technique can be implemented without any prior knowledge of PU signal, it still has some limitations. The first issue is its poor detection performance under low SNR conditions it is due to the noise power uncertainty. Another is inability to distinguish the interference from the other SU's sharing the same channel and the PU.

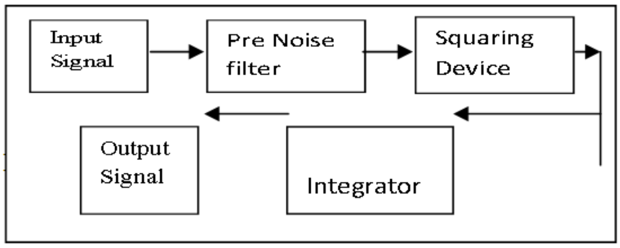


Fig.2. Block Diagram Energy detector

**E. Other Spectrum Sensing techniques**

Some other alternative spectrum sensing techniques includes Cooperative spectrum sensing in which multiple cognitive radios users collaborate either xz by sending their decision statistics or the final 1 bit decision to a Fusion Center (ex. a base station) and the final decision is done by the base station. This method is more dominant than other methods in a sense that it provides multiuser diversity and reduces the Hidden Node Problem, which occurs either when a primary user is shadowed by an barrier, so that the cognitive user cannot detect it, which results in cognitive user to transmit in the same spectrum band with the primary user, causing high interference to it. Cooperative sensing is usually performed by cognitive users each with an energy detector. Multi-taper spectral estimation, Collaborative spectrum sensing, OFDM and MIMO spectrum sensing techniques has been presented in [6] various research papers to improve the performance of spectrum sensing analysis with other features and benefits. We have focused on energy detection and further we can used energy detection with cooperative spectrum sensing in different ways such as hard and soft combination which will improves the detection performance.

## III. System Model

### A. PU signal detection

The fundamental nature of spectrum sensing is binary hypothesis-testing problems consider as H0 and H1 shows the PU absent and PU present respectively[12]. The main parameters of the spectrum sensing are the probabilities of correct detection given by $P_d\{\text{decision}, v = H_1|H_1\}$ and $P_d\{\text{decision}, v = H_0|H_0\}$, the false alarm probability is given by $P_{fa}\{\text{decision}, v = H1|H0$ and the missed detection probability $P_m\{\text{decision} = H_0|H_1\}$.To understand all these parameters we consider [10] a CR network having K CR users (SU i.e. secondary user) and a common receiver as shown in fig 2. The main function of common receiver is to manage the CR network and all the K CRs present in it. We believe that each CR performs local spectrum sensing independently. The PU signal spectrum sensing problem is to decide between the following two hypotheses.

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$$y(i)=\begin{cases} n(i), & H_0\ PU\ is\ absent \\ hx(i)+n(i), & H_1\ PU\ is\ presnt \end{cases} \quad (1)$$

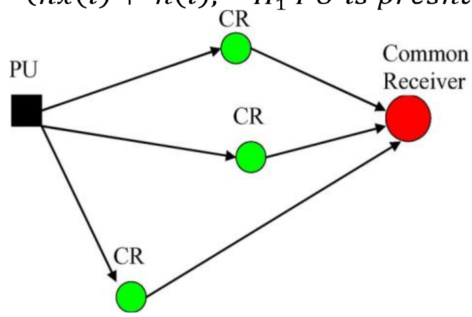


Fig.3. Spectrum sensing in a cognitive radio network

where $i=0,1,\ldots..M$ number of samples, $n(i)$ is the background noise of the $i^{th}$ sample. Suppose that noise is independent and identically distributed (AWGN) i.e. $n(i)\sim N(0,\sigma_n^2)$ (zero mean and unit variance, $\sigma_n^2=1$), $x(i)$ is the PU's signal at $i^{th}$ sample, M is number of samples, $y(i)$ is the signal detected by sensing node or SU's, h is the channel gain between PU and SU. The noise can be estimated but the signal power is difficult to estimate as it changes depending on ongoing transmission characteristics and the distance between the SU and PU. Thus, the knowledge of noise variance is sufficient for the selection of threshold $(\eta)$. The SNR (Signal to Noise Ratio) is denoted by $\gamma_i=\frac{\sigma_s^2}{\sigma_n^2}$, where $\sigma_s^2$ represents transmitted signal power and $\sigma_n^2$ represents noise power.

The detection algorithm can be formulated as $P_d=P_r(v>\eta|H_1)$ and the false alarm probability is given by $P_{fa}=P_r(v>\eta|H_0)$ and the missed detection probability $P_m=1-P_d$ and probability of error is given as $P_e=P_m+P_{fa}$.

## B. Energy Detection

The Energy Detection presented in [8] and [9] spectrum sensing techniques is performed for the above PU signal detection in such manner by measuring the energy of the received signal $y(i)$ in a fixed bandwidth W over a time window T. The energy collected in the frequency domain is denoted by decision, v which serves as decision statistics here and given by

$$v\sim\begin{cases} X_{2u}^2, & H_0 \\ X_{2u}^2(2\gamma_i), & H_1 \end{cases} \quad (2)$$

$H_0$: refers to the case when there is no PU present,

$H_1$: refers to the case when currently band is occupied by PU's

Where $X_{2u}^2$ denotes a central chi-square distribution with 2u degrees of freedom and $X_{2u}^2(2\gamma_i)$ denotes non-central chi-square distribution with u degrees of freedom and if non-centrality factor $\mu=\frac{E_s}{N_O}$, Signal to Noise ratio, then $\gamma_i=\mu/2$ and $\mu=2\gamma_i$, such that SNR value for ith sample, $\gamma_i=\frac{\sigma_s^2}{\sigma_n^2}$ and Time- Bandwidth product, u =TW. Thus the problem can be formulated as a binary hypothesis testing as output of energy detector gives the test statistics T

$$T=\frac{1}{M}\sum_{i=1}^{M}|x(i)|^2\begin{cases}\geq\eta, H_1\\ <\eta, H_0\end{cases} \quad (3)$$

Where $\eta$ is the threshold value, if $T\geq\eta$, $H_1$ is true, otherwise $T<\eta, H_0$ however, in practical system.

### Over AWGN Channel

Energy detection was studied in [8] and [9] in which 2TW samples were used to detect the presence of a signal of time duration T and band limited to W. The basic energy detector is shown in Fig. 2 the test statistics is shown in above equation (3)

$$P_{fa}=Q\left((\eta-1)\sqrt{\frac{M}{2}}\right), \quad (4)$$

$$P_d=Q\left((\eta-\gamma_i-1)\sqrt{\frac{M}{2(\gamma_i+1)^2}}\right), \quad (5)$$

$$P_m=1-P_d \quad (6)$$

Where $Q(.)$ is the Marcum Q- function given by $Q(a)=\frac{1}{\sqrt{2\pi}}\int_a^{\infty}\exp\left(\frac{-z}{2}\right)^2dz$

### Over fading environment

### Rayleigh Fading Channel

The energy detection over fading channel was studied in [8], in which the probability of detection for a given SNR $(\gamma)$ was integrated over the pdf of the SNR of the Rayleigh fading channels, which is known to have an exponential distribution given as

$$f(\gamma)=1/\gamma'\exp\left(-\frac{\gamma}{\gamma'}\right)$$

$$P_d=e^{\eta/2}\sum_{i=0}^{\frac{U}{z}-2}\frac{\left(\frac{\eta}{2}\right)^i}{i!\,(1+\frac{\gamma}{\gamma'})^{\frac{U}{2}-1}*[e^{\eta/2(1+\gamma)}]}-e^{\eta/2}\sum_{i=0}^{\frac{U}{z}-2}\frac{\left(\frac{\eta}{2}\right)(1+\gamma')}{i!}$$

Where $\gamma'$ is the average SNR and N/2 is the time bandwidth product.

### Nakagami Fading Channel

In Nakagami channels the energy detection is found in by integrating the probability of detection for a given [8] and [9] SNR over the Nakagami distribution which is given below in

$$f(\gamma)=\frac{1}{m!}\left(\frac{m}{\gamma}\right)^m\gamma^{m-1}\exp\left(-\frac{m}{\gamma'}\gamma\right),\gamma\geq 0$$

$$P_d=A_1+\beta^m e^{-\eta/2}*\sum_{I=1}^{\frac{U}{2}I}\left(\frac{\eta}{2}\right)^I/i!\,F_1\left(m,i+1,\frac{\eta(1-\beta)}{2}\right)$$

Where $\beta=m/(m+\gamma)$

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$F_1(.;.;)$ is the confluent hyper geometric function and m is the Nakagami order such that $A_1 = e^{\eta\beta/2m}[\beta^{m-1}L_{m-1}\left(-\frac{\eta(1-\beta)}{2}\right) + (1-\beta)\sum_{j=0}^{m-2}\beta\, i\, L_i\left(-\frac{\eta(1-\beta)}{2}\right)]$

To simplify the sensing algorithms, x(i) is usually assumed to be an independent and identically distributed Gaussian random process with mean zero and variance (x(i) = P).Then the output of the energy detector.

### C. Cooperative Energy Spectrum Sensing

Due to Interference factors such as multipath propagation and the shadow effect in wireless channels, energy sensing performed by single cognitive sensing node (SU's) with low SNR of the received signal may be unpredictable. To reduce this problem CESS is proposed in [13] and[15]the cooperative sensing algorithms in CR networks can be categorized into two categories i.e soft fusion and hard fusion [12].

**CSS based on Soft decision fusion**

In this paper, we reviewed both soft fusion and hard fusion. First we go with soft fusion algorithms, the distributed sensing nodes send soft information (e.g. likelihood ratio or received signal power) to the sensing station and the sensing station makes an overall decision based on [14] individually gathered information from sensing nodes under certain rules. Assuming $N$ as the number of sensing nodes and $T_k$ as the energy output of the $k$-th sensing node (SU's), the average weight linear cooperative spectrum sensing algorithm is as follows:

$$\overline{T} = \begin{cases} \frac{1}{N}\sum_{k=1}^{N} T_k < \eta,\ H_0 \\ \frac{1}{N}\sum_{k=1}^{N} T_k \geq \eta, H_1 \end{cases} \tag{7}$$

On increasing the weight factors of the sensing nodes with higher received SNR can improve the performance of CSS. For weight based SNR above equation will be written as

$$\overline{T} = \begin{cases} \frac{1}{N}\sum_{k=1}^{N} T_k.w_k < \eta,\ \ H_0 \\ \frac{1}{N}\sum_{k=1}^{N} T_k.w_k \geq \eta,\ \ H_1 \end{cases} \tag{8}$$

where $w_k = \frac{SNR_k}{\sum_{r=1}^{N} SNR_r}$

When the sensing nodes send received signal sequence to $y_k = [y_k(1), y_k(2), y_k(3), \ldots \ldots y_k(M)],\ \ k = 1,2, \ldots\ldots N$ the sensing nodes, it was demonstrated in Ref. [11] that the optimal energy spectrum sensing algorithm is:

$$T(Y) = YC(C + \sigma^2 I)^{-1} Y^H > \eta$$

*Where* $Y = [Y_1\, Y_2\, Y_3 \ldots\ Y_N] = [y_1(1) \ldots y_1(N) \ldots y_N(M)$ *and*

$C =$

$$E([h_1X\ h_2X\ h_3X \ldots h_MX]^H[h_1X\ h_2X\ h_3X \ldots h_MX]) = \begin{bmatrix} E((h_1X)^H h_1X) & E((h_1X)^H h_2X) \ldots & E((h_1X)^H h_MX) \\ \ldots & \ldots & \ldots \\ E((h_MX)^H h_1X) & E((h_MX)^H h_1X) \ldots & E((h_MX)^H h_MX) \end{bmatrix}$$

**CSS based on hard decision fusion**

All CR's recognize the availability of the licensed spectrum independently. In [16] each cooperative collaborator makes a binary decision based on its local detection and then forwards one bit of the decision to the common receiver.

Suppose $D_i \in \{0,1\}$ is the local spectrum result of ith CR where 0 shows the absence of PU and 1 shows the presence of PU.

At common receiver all 1-bit decision are fused together according to next law

$$Z = \sum_{i=1}^{k} D_i \begin{cases} \geq \eta, H_1 \\ < \eta, H_0 \end{cases} \tag{9}$$

where $H_1$ & $H_0$ represents the interference drawn by the common receiver that the PU signal is transmitted or not transmitted.

$H_1$ When there are atleast $n$ out of $K$ CR's inferring$H_1$.

$H_0$ Otherwise common receiver decides the PU signal not being transmitted,

In [12] hard decision fusion, we have three decision fusion rules as described in above sections for OR rule n=1, the common receiver infers the presence of the PU signal when there is at least one CR user that has local decision$H_1$, in case of AND rule when all CR's involved in the sensing and all of them having $H_1$as their local decision whereas in the last case of Voting (or Majority) rule if at least M of the K CR user's have detected a PU signal and gives $H_1$ as their local decision. Also we can say that M=1 is a special case of Voting rule that gives OR rule similarly M=K is a special case of Voting rule which gives AND rule. Now the false alarm probability of CSS based on OR rule is given by

$$P_{fa} = 1 - \prod_{i=1}^{k}(1 - P_{fa}^{(i)}) \tag{10}$$

$P_{fa}^{(i)}$ is a false alarm probability of the $i$th CR in its local spectrum sensing.

The missed detection probability of CSS given by

$$P_m = \prod_{i=1}^{k} P_m^{(i)} \tag{11}$$

$P_m^{(i)}$ is the missed detection probability of the CR in its local spectrum sensing. Suppose that every CR achieves identical $P_{fa}$ & $P_m$ in the local spectrum sensing (i.e. $P_{fa} = P_{fa}^{(i)}$ *and* $P_m = P_m^{(i)}\ \forall\ i = 1,2,3 \ldots .k)$

## IV. Simulation and Results

This section primarily depicts the simulation setup used, to evaluate the performances of the methods proposed in Section III. A comprehensive analysis of the sensing performance parameters, including sensitivity, accuracy, efficiency, complexity and energy are executed for energy detection over AWGN channel and Fading

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channels (Rayleigh and Nakagami-m), also Cooperative spectrum sensing with hard combination using AND rule under AWGN channel [10]. Both Energy Detection and CSS techniques are exploited and analyzed. Then a comparative study is done considering all the different parameters under energy detection and CSS over AWGN channel. Thus, the detection performance in [11] spectrum sensing is crucial to the performance of both primary and CR networks and detection performance assessed through the following metrics: i) Probability of Detection ($P_d$): It denotes the probability of a CR user defining that a PU is present when the spectrum is really occupied by the PU. For better performance it should be high in value. ii) Probability of False Alarm ($P_{fa}$): It denotes the probability of a CR user defining that the CR detects that the spectrum is occupied when it is actually free. For better performance it should be low in value.iii) Probability of Miss-detection ($P_m$): It denotes the probability of a CR user defining that the CR detects that the spectrum is free when the spectrum is actually in use by the PU. It causes interference with PU. For better performance it should be zero. iv) Detection Delay($\tau$): This parameter is with respect to the average number of samples the detector takes to make a decision whether PU is present or absent.

A miss in detection guides to interference to PU and a false alarm will decrease spectral efficiency. Concerns like receiver uncertainty problem, multipath fading, shadowing mainly influence the detection performance. In addition spectral holes require to be detected at very low SNR (<20 dB). Further, the measurement setup to validate the simulation results is presented here for energy detection over AWGN channel and Fading channels, also CSS using AND rule with both measured and simulated spectrum is plotted. In this section we described all the simulation results with their plots in detail.

**A. Performance analysis of Energy Detection**

In order to compare the performances of different threshold values, receiver operating characteristic (ROC) curves and Complementary ROC curves allow us to explore the relationship between probability of detection and false alarm of a sensing technique for different values of threshold. The number of used samples is set to N=1000, with $P_{fa}$=0.001 in fig.4 and 0.2 in fig.5, which clearly shows the performance of the energy detection increases as SNR values increases from positive to negative under AWGN channel.

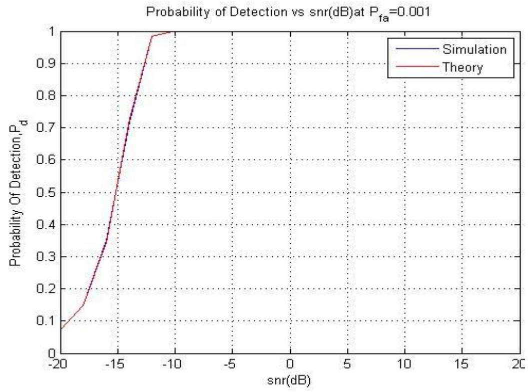


Fig.4. Probability of Detection vs. SNR (dB) at $P_{fa}$=0.001 for AWGN

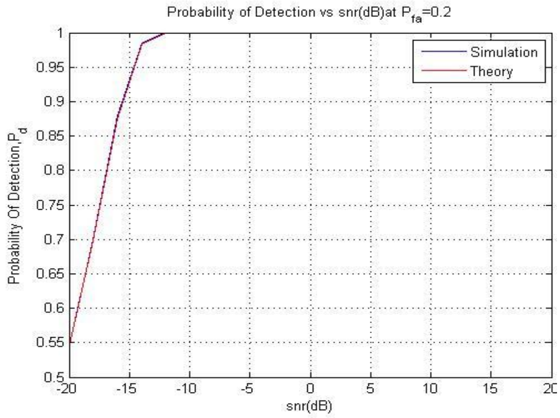


Fig.5.Probability of Detection vs. SNR (dB) at $P_{fa}$=0.2 for AWGN

If we consider the same values for Rayleigh and Nakagami fading channel then in fig.6 and fig.7 similar plot is shown for the Rayleigh channel reflects that it has better performance than Rayleigh channel at low SNR values.

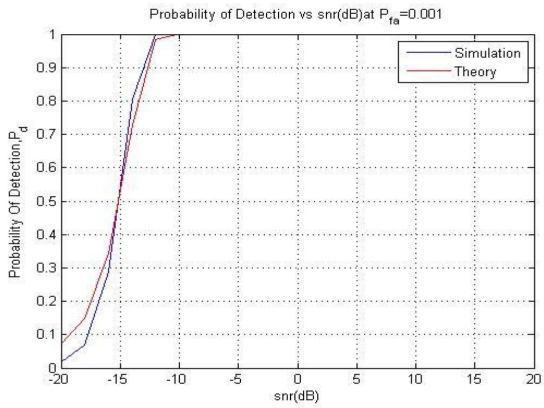


Fig.6. Probability of Detection vs. SNR (dB) at $P_{fa}$=0.001 for Rayleigh

The energy detector capabilities demean rapidly when the average SNR or SNR of the channel reduces from 20dB to -20dB, further there is relevance performance

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degradation of the energy detector due to the effect of shadowing in higher average SNR. The performance of any spectrum sensing technique considerably depends upon the SNR values experienced by the sensing terminals and to evaluate the performance we can vary the value of SNR for all SUs and compute the detection performance.

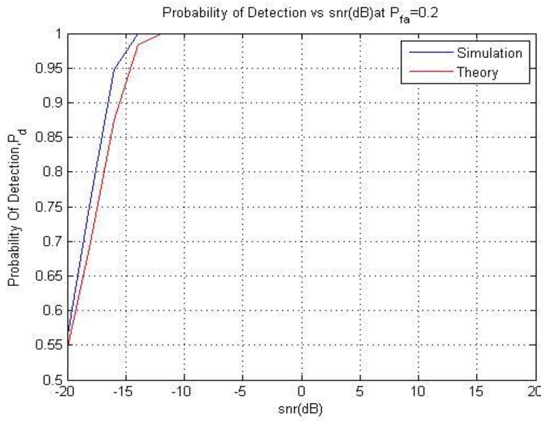


Fig.7.Probability of Detection vs. SNR (dB) at $P_{fa}$=0.2 for Rayleigh

Similarly, for Nakagami channel we have fig.8 at $P_{fa}$=0.001 and fig.9 at $P_{fa}$=0.2 which shows better performance results as compare to the Rayleigh and AWGN channel.

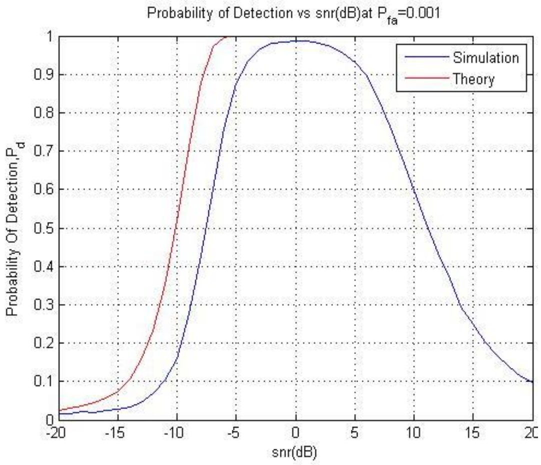


Fig.8.Probability of Detection vs. SNR (dB) at $P_{fa}$=0.001 for Nakagami

In above graph the Probability of Detection versus SNR (in dB) is shown for the Probability of False Alarm *$P_{fa}$=0.2 and 0.01*, respectively. The result shows that the probability of detection is increased with increase of SNR values.

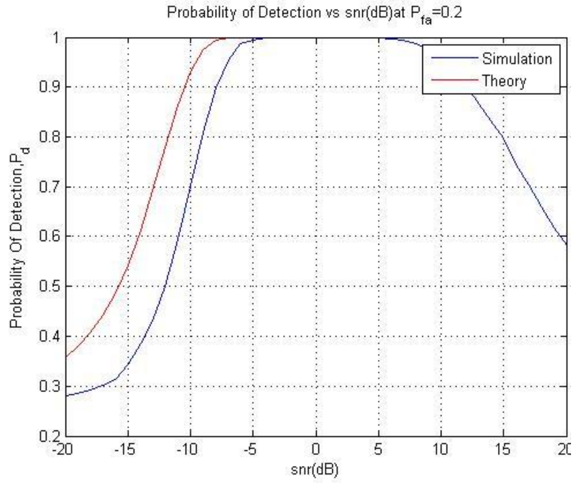


Fig.9.Probability of Detection vs. SNR (dB) at $P_{fa}$=0.2 for Nakagami

The performance of energy detection is evaluated Energy detection is the technique used for sensing the spectrum of PU in the AWGN channel and in fading environment (Rayleigh and Nakagami) using Monte Carlo simulation for the experimentation under the following system element values: there are 10 randomly distributed Gaussian channels with zero mean and unity variance and SU looking for spectrum holes in these channels. In fig.10 shows the ROC plots for Probability of Detection and Probability of False Alarm respectively with the network at SNR=-10dB under AWGN channel.

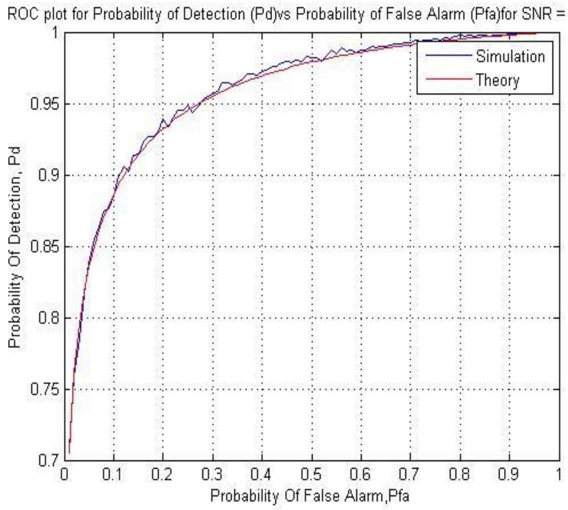


Fig.10.ROC for $P_d$ vs. $P_{fa}$ , at SNR (dB) =-10dB for AWGN

In similar simulation with the Rayleigh channel fig.11 shows the ROC plot for Probability of Detection and Probability of False Alarm at SNR=-10dB.

Finally on considering the plots we got to know that the performance of AWGN channel is much better than the

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Rayleigh channel as we getting similar plots for theory and simulation in AWGN further we can make more simulation by varying the values of parameters also we can do the same analysis of ROC plots for Probability of Detection and Probability of False Alarm under Nakagami channel.

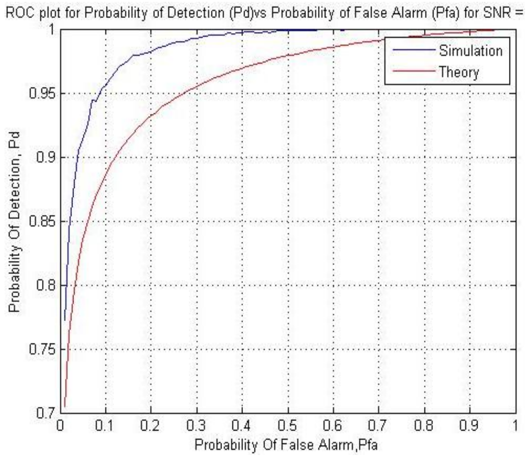


Fig.11.ROC for $P_d$ vs. $P_{fa}$ , at SNR (dB) =-10dB for Rayleigh

For a particular value of SNR, high $P_{fa}$ results in a low probability of miss detection because of the reduced threshold. Now, further we take some plots for the complementary ROC of Probability of Miss detection and Probability of false alarm at SNR=-10dB with N=1000 as shown in fig.12 for AWGN channel.

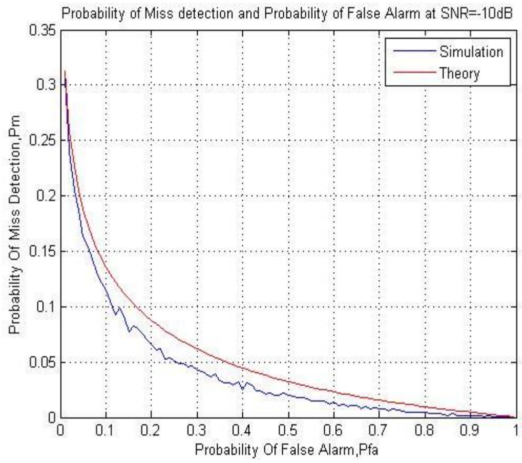


Fig.12.Complementary ROC for $P_m$ vs. $P_{fa}$ at SNR=-10dB for AWGN

Then, for Rayleigh channel we have fig.13 as shown below in which we can see that how the analysis is made for the simulation and theory in the curve.

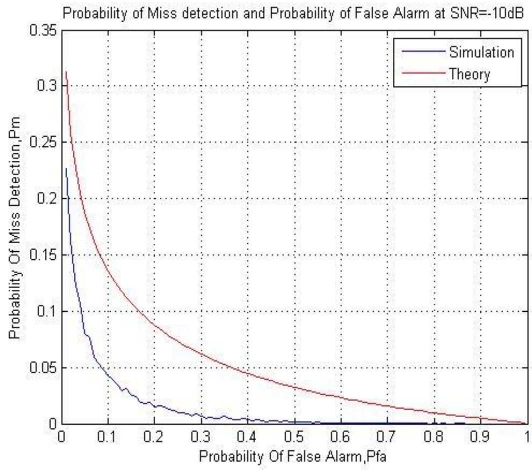


Fig.13.Complementary ROC for $P_m$ vs. $P_{fa}$ at SNR=-10dB for Rayleigh

Next we have performed the analysis for probability of error defined in previous chapter draws some curves under AWGN channel and fading environment.

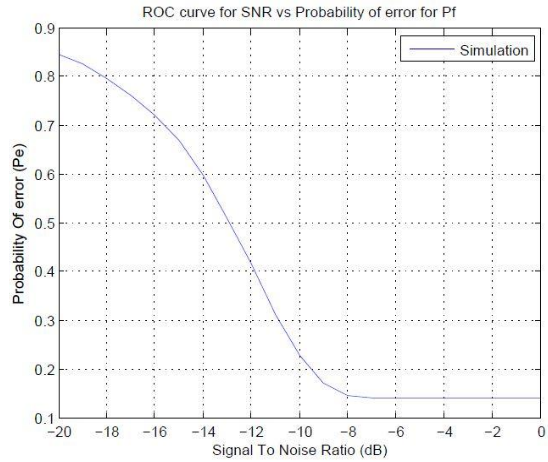


Fig.14.ROC curve for Probability of Error vs SNR for AWGN

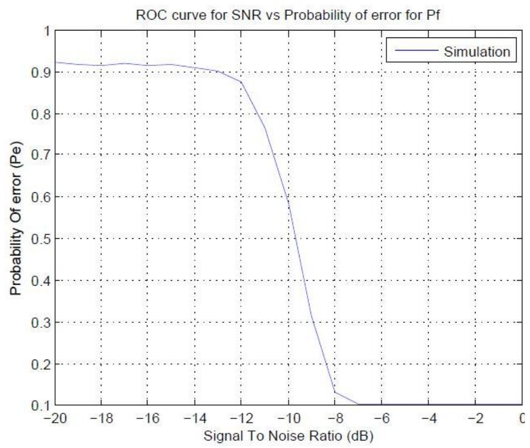

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Fig.15.ROC curve for Probability of Error vs SNR for Nakagami

If we consider the above fig.14 and fig.15 we found that the probability of error becomes zero as SNR is high or having any positive value which means that it easy to detect the presence of SU under high SNR irrespective of the fading environment. Further we have performed the analysis for total error rate and threshold in energy detection in fig.16 as given.

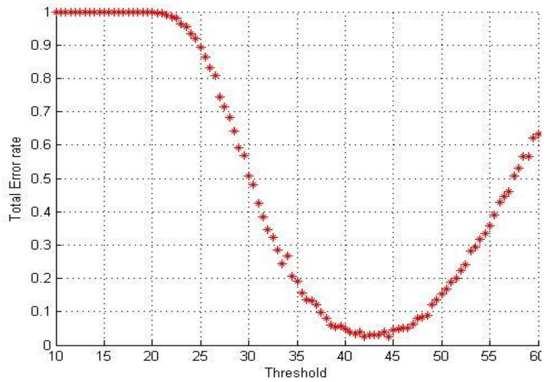


Fig.16.Total error rate vs Threshold in energy detection

Comparing the AWGN curve with those corresponding to fading environment, we observe that performance of spectrum sensing degrades in fading environment.

### B. Performance analysis of CSS

In this section we have performed the analysis of CSS with hard combination using AND rule In fig.17 we analysis the sensing performance under the target probability of miss detection and probability of false alarm at SNR=-15dB and N=1000, n=10 and n=5 (no. of SU's).

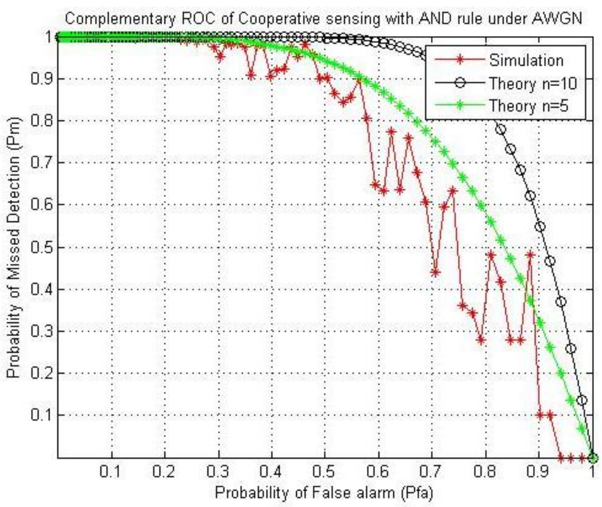


Fig.17.Complementary ROC with AND rule AWGN for SNR=-15 dB

## V. Conclusion and Discussion

Spectrum is a very precious resource in wireless systems and applications, and it has been a central point for research over the last several decades. Cognitive Radio is a novel technology that can potentially improve the utilization efficiency of the radio spectrum. In this paper, several spectrum sensing techniques have been reviewed and a comparison is made. But, special attention has been given to Energy Detection because of its low computational complexity, it does not require any prior knowledge of PU signal and Cooperative Spectrum Sensing (CSS) as it improves the detection performance under severe fading and hidden terminal problem. Cooperative spectrum sensing is better than classical spectrum sensing techniques as it overcomes the hidden node problem, reduces false alarm and gives more accurate signal detection. To analyze the performance of energy detection algorithm for spectrum sensing in cognitive radio by drawing the ROC (Receiver Operating Characteristics) and complementary ROC curves between probability of false alarm vs. probability of detection, SNR vs. probability of detection, Probability of error vs. Threshold in cognitive radio systems. We have analyzed the performance of energy detection over AWGN channel and over fading environment (Rayleigh, Nakagami-m,). We considered the challenges of multipath fading and hidden terminal problem. To overcome it we studied and presented cooperative spectrum sensing with soft and hard combination over AWGN channel. Finally cooperative Energy spectrum sensing (CESS) detection based on hard decision with AND rule evaluated which shows better results in different situations.

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